Conversion of Fertilized Annual Range Forage to Beef Cattle Liveweight Gain

C. A. Raguse,* K. L. Taggard, J. L. Hull, J. G. Morris, M. R. George, and L. C. Larsen

ABSTRACT

A 3-yr field experiment evaluated average daily (ADG) and total seasonal (LG) weight gains of growing beef cattle (*Bos taurus*) on fertilized California foothill annual range. Soils were a mixture of four series of alfisols. Nitrogen was applied alone at 45 or 90 kg ha^{-1}, P and S were applied together at 34P 37S or 67P 74S kg ha^{-1}, and the two N rates were combined with 34P 37S. Two 13.2-ha replications were stocked with 215-kg steers in late November, and stocking rates were increased twice during a grazing season averaging 190 d. Forage on offer (FL) varied from 400 to 2500 kg ha^{-1}. Annual forage production (FP) varied from 2500 to 5700 kg ha^{-1} and differed ($P<0.05$) between treatments and years. Year-to-year and within-year variations in rainfall influenced FP. Average daily gains over the season varied linearly from less than 0.2 to over 1.0 kg steer^{-1}. Differences in ADG due to treatments were largely restricted to the first year and to treatments with N, P, and S or the higher level of PS, but 3-yr trends were not significant. Average daily gain was not strongly influenced by either FL or legume content of the forage. Three-year LG was highest for the two NPS and the higher PS treatment. Fertilization increased forage organic matter digestibility and N concentrations over the control. Results indicate that either N, P, and S or a sufficient level of P and S to stimulate production of legume N was required for high forage production.

Additional Index Words: **Nitrogen, Phosphorus, Sulfur Fertilization, Forage allowance, Annual grasses, Annual legumes, Annual forbs, Average daily gains.**

IMPROVED animal product yield from California's Mediterranean climate foothill annual rangeland has been accomplished through vegetation-type conversion (9), re-seeding with exotic species of annual legumes and perennial grasses (11), and concurrent correction of major soil nutrient deficiencies (notably N, P, and S) (13). Longer-term maintenance practices included controlled grazing (8) and re-application of soil nutrients (29). In California's annual grasslands it is common for the latter to be done at intervals of from 2 to 5 yr (3,22,29,30; M. Bell, 1987, personal communication). The considerable emphasis given to introduction of annual legumes had as one result the widespread occurrence of managed range plant communities comprised of three annual-species groups: grasses, legumes, and forbs. The latter is most commonly filaree (*Erodium* sp.), a relatively palatable and nutritious forage.

Numerous investigators have concluded that year-to-year and within-year weather variation can be the principal determinant of system yield (2,5,7,10,19). Of most frequent importance is variation in between- and within-season precipitation (5,12,17). Murphy (19), in an area with rainfall similar to ours (average annual precipitation 890 mm), analyzed a 16-yr data set and found total seasonal plant production to be well correlated with rainfall accumulated by 20 November (a minimum of 200 mm). Duncan and Woodmansee (5), in an area with lower average annual rainfall (480 mm) and greater year-to-year variation (260–830 mm), obtained forage yield/monthly precipitation correlations for grasses, legumes, and nonlegume forbs (principally *Erodium* sp.) from a 34-yr data set. The one, two, and three months best correlated to legume yield were April; November and April; and November, April, and May, respectively.

Where precipitation is not limiting, fertilization of rangeland has been used to increase both yield and quality. Martin and Berry (17) investigated first- and second-year steer per area liveweight gain (LG) responses to the addition of N, NS, or NP fertilizers, with particular emphasis on the relationship of LG to N. First-year LG (Y = kg ha^{-1}) results were generalized to the predictive equation, $Y = 1.0X + 57.5$ (X = kg N ha^{-1}). Second-year results were approximately

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50% of first-year gains attributed to N, if annual rainfall did not exceed 760 mm. Jones (12) also reported lack of residual effect of N applications up to 179 kg ha^{-1} in 2 yr where previous annual rainfall totals were 800 and 1025 mm.

Jones et al. (15) found that soil fertility was more closely related to yield in annual grasslands than a number of physical site-soil factors, with soil P most consistently related to forage production. Vaughn and Murphy (29) concluded from a 20-yr study that fertilization of subclover (*Trifolium subterraneum* L.)-grass pastures increased forage production during the critical winter period and minimized between-year production variation. Caldwell et al. (2) found that S fertilization increased legume production but filaree was unaffected. Fertilization of legume-based annual rangelands has been shown to increase the quality of forage for sheep (*Ovis aries*) and lamb production (3,14,25). In one of the few studies using cattle, Wolters and Eberlein (30) observed earlier readiness for grazing and significantly greater LG, but S or N and S fertilization did not result in larger average daily gains (ADG). Where legumes comprise an important component of vegetation, both fertilization and grazing management can influence animal productivity through effects on legume content (16).

The objective of this experiment was to compare the influence of N, PS, and NPS fertilization on plant growth and quality, grazing animal performance, and botanical stability of the plant community. The study was designed to account for three consecutive whole seasons of grazing at known levels of forage allowance.

MATERIALS AND METHODS

The experiment was conducted at the University of California's Sierra Foothill Range Field Station, Browns Valley, Yuba County, in the lower foothill oak (*Quercus* spp.) woodland zone of the northern Sierra Nevada mountains. Herbaceous vegetation, which is almost completely annual, is a variable mixture of grasses, legumes and forbs. The field site was at an approximately 330-m elevation at 39° 14′ N 121°18′ W.

An average 750 to 900 mm of rainfall (snowfall is very rare and transient) is received between mid-October and late April in a typical Mediterranean climate. Standard weather observations were collected at the Station. Figure 1 presents rainfall distributions for the 3 yr of the experiment.

The soils are fine to fine-loamy, mixed, thermic Mollic Haploxeralfs or Typic Rhodoxeralfs. The only previous fertilizer application was made from 1971 to 1974, when 112 kg ha^{-1} of single superphosphate (22 and 13 kg ha^{-1} of P and S, respectively) was applied when drill-seeding annual legumes.

Using a randomized block design, two replications of seven fertilizer treatments were applied as follows:
(i) a control
(ii) 45 kg ha^{-1} N
(iii) 90 kg ha^{-1} N
(iv) 45 kg ha^{-1} N, 34 kg ha^{-1} P, and 37 kg ha^{-1} S
(v) 90 kg ha^{-1} N, 34 kg ha^{-1} P, and 37 kg ha^{-1} S
(vi) 0 kg ha^{-1} N, 34 kg ha^{-1} P, and 37 kg ha^{-1} S
(vii) 0 kg ha^{-1} N, 67 kg ha^{-1} P, and 74 kg ha^{-1} S

All fields were 13.2 ha in size. Four fields were used for the control, averaging data from two fields for each of the two replications. Each replication of the fertilizer treatments was a single field.

Nitrogen was applied as urea, and P and S were applied as a mixture of two formulations of single superphosphate (0-20-0-12S and 0-25-0-10S). With slightly acid soils (pH = 5.9) and cool weather during the growing season, volatilization losses of urea were considered inconsequential (M.B. Jones, 1982, personal communication). The N- and PS-carrying materials were separately applied by helicopter on 5 and 6 Oct. 1982. The 3 yr of the experiment allowed for estimation of nutrient carryover and for an assessment of fertilization effects on plant species composition.

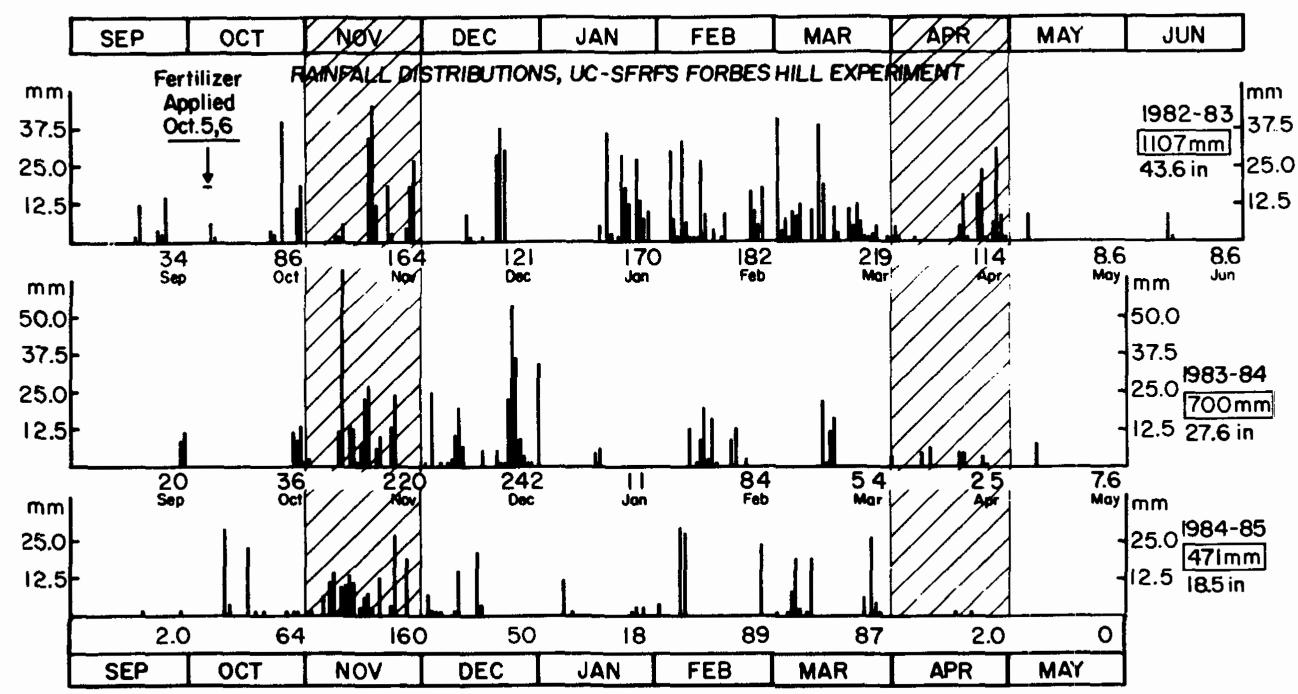

Fig. 1. Intra-seasonal distribution of rainfall and seasonal totals for growing seasons within the 3 yr of the experiment. November and April are months found to be best correlated with legume and total forage yields (5).

Soil samples (0–150 mm) were taken from all fields prior to fertilization and 40 samples were combined to four replications for each field. The average $NaCO_3$-extractable P was 5 mg kg^{-1}, and pH was 5.9. The average extractable cations (neutral-normal ammonium acetate) were: Ca, 3200; Mg, 360; Na, 230; and K, 117 mg kg^{-1}. Previous work has shown that these soils have a high P-fixing capacity (21). A standard greenhouse pot test using a representative annual grass-clover mixture showed that N, P, and S all were required for optimal growth (24).

The area had been seeded previously with a mixture of subterranean and rose (*T. hirtum* L.) clovers (1971–1974). Botanical composition (point quadrat, first live forage hit) was measured along two 200-m permanent transects (100 points per transect) in each field once per season in early April. Levels of forage on offer (FL) were monitored immediately prior to each animal weigh date (WD) (November–May) throughout the grazing season along the same transects, using a Neal model 3000 capacitance forage meter (Burbank, CA) or a mechanical pressure plate. Each device was calibrated by double-sampling each sampling time to correct values to a dry-matter (DM) (70°C, 48-h) basis. Levels of residual, dry, mature forage also were measured during mid-summer. Total seasonal forage production (FP) was estimated from stocking weights, assuming animal intake as 2.5% of bodyweight (18) and adding to that value current-season plant residue remaining at the final WD.

Each year medium-frame, mostly No. 2 muscle thickness, yearling beef feeder steers of mixed English breeding were purchased. Yearling heifers, predominantly Hereford and of the same quality, were taken from the station herd. Standard veterinary practices were used to maintain animal health. All animals were allowed a 21- to 42-d adjustment period prior to random allotment to grazing treatment replications. Prior to all weighings animals were held overnight without feed and water.

Beginning mid- to late November, each field was uniformly stocked with steers (initial weight approximately 215 kg) at 1.65 to 3.3 ha steer^{-1} (Table 1). Two subsequent increases in stocking rates within each season were based on FL measured along permanent transects in each field. No animals were removed before the end of the grazing season, i.e., all animals were considered as testers. Heifers (of initial weights similar to those of the steers) were also used for part

Table 1. Stocking rates, forage levels, forage allowance, and average daily gains for a control and three treatment combinations for an initial and eight weigh periods over 3 yr.

Weigh date	Stocking rate				Forage level				Forage allowance				Avg. daily gain			
	Control	N-only	NPS	PS-only	Control	N-only	NPS	PS-only	Control	N-only	NPS	PS-only	Control	N-only	NPS	PS-only
	ha animal^{-1}				kg ha^{-1}				kg kg^{-1}				kg steer^{-1} d^{-1}			
							1982–1983 Season (196 d)									
3 Dec.	3.30	3.30	3.30	3.30	850	970	1470	930								
7 Jan.	1.32	1.15	0.81	1.26	1120	1350	1860	1230	9.4	10.1	11.6	9.9	0.29	0.52	0.41	0.43
4 Feb.	1.32	1.15	0.81	1.26	1090	1230	1550	1160	5.9	5.9	5.5	6.0	0.53	0.75	0.78	0.65
4 Mar.	1.10	0.73	0.47	0.94	1020	1170	1510	1410	4.9	4.1	3.6	5.1	0.66	0.80	0.79	0.74
25 Mar.	1.10	0.73	0.47	0.94	1230	1280	1610	1660	4.3	3.0	2.4	4.7	0.87	1.05	1.00	0.98
15 Apr.	1.12	0.73	0.47	0.94	1920	1750	1980	2600	5.7	3.4	2.6	6.3	0.93	0.95	1.07	1.08
6 May	1.12	0.73	0.47	0.94	2670	2630	2890	4780	7.9	4.7	3.3	10.2	0.98	1.05	0.99	1.08
27 May	1.10	0.88	0.83	0.46	2580	2630	3040	5290	8.5	5.6	4.4	9.7	0.82	0.68	0.75	0.84
16 June	1.10	0.88	0.83	0.46	2140	1890	2270	4010	7.3	5.3	5.9	5.8	0.17	0.19	0.30	0.52
LSD (0.05)	ADG												0.17†			
Mean	1.40	1.14	0.94	1.17	1624	1656	2020	2563	6.7	5.3	4.9	7.2	0.66	0.75	0.76	0.79
LSD (0.05)	Mean ADG												0.06‡			
							1983–1984 Season (190 d)									
22 Nov.	2.20	2.20	2.20	2.20	430	460	590	540								
20 Dec.	1.65	1.65	1.65	1.65	430	450	530	420	3.9	4.2	5.1	4.4	0.46	0.41	0.43	0.48
18 Jan.	1.65	1.65	1.65	1.65	420	390	460	450	3.1	3.1	3.6	3.2	0.44	0.61	0.61	0.50
7 Feb.	1.65	1.65	1.65	1.65	680	610	720	730	3.8	3.4	4.0	4.1	0.70	0.85	0.85	0.81
28 Feb.	1.15	1.23	0.98	1.00	750	720	910	870	4.1	3.8	4.3	4.5	0.74	0.75	0.83	0.78
28 Mar.	1.12	1.23	0.98	1.00	1060	1060	1350	1410	4.3	4.1	4.2	4.5	0.93	1.02	1.13	0.99
17 Apr.	0.86	0.89	0.67	0.68	1920	1870	2260	2550	5.5	5.3	5.1	5.9	0.93	1.00	1.10	0.99
8 May	0.86	0.89	0.67	0.68	2490	2290	2860	2990	6.1	5.8	5.2	5.9	1.11	0.90	1.05	1.14
30 May	0.86	0.89	0.67	0.68	1470	1350	1640	1750	5.3	4.8	4.4	4.9	0.17	0.35	0.19	0.14
LSD (0.05)	ADG												0.19†			
Mean	1.33	1.36	1.24	1.24	1072	1022	1258	1301	4.5	4.3	4.5	4.7	0.69	0.73	0.77	0.73
LSD (0.05)	Mean ADG												0.07‡			
							1984–1985 Season (183 d)									
29 Nov.	1.65	1.65	1.65	1.65	950	770	960	860								
20 Dec.	1.65	1.65	1.65	1.65	780	730	830	710	6.2	6.2	6.4	5.7	0.37	0.34	0.42	0.39
17 Jan.	1.65	1.65	1.65	1.65	1030	1000	1080	970	6.1	6.0	6.4	5.7	0.71	0.69	0.86	0.81
14 Feb.	1.10	1.10	1.10	1.10	880	870	930	850	5.0	5.0	5.2	4.8	0.31	0.60	0.65	0.59
7 Mar.	1.10	1.10	1.10	1.10	730	720	900	800	3.1	3.2	3.5	3.2	0.84	0.76	0.88	0.90
28 Mar.	1.10	1.10	1.10	1.10	1190	1030	1350	1320	3.5	3.3	4.0	3.9	0.70	0.59	0.70	0.72
17 Apr.	0.54	0.60	0.44	0.49	1930	1720	1990	2190	4.1	3.9	4.0	4.4	0.99	0.83	0.93	1.01
9 May	0.54	0.60	0.44	0.49	1340	1500	1560	1520	3.1	3.1	2.5	3.2	0.91	0.83	0.90	1.01
30 May	0.54	0.60	0.44	0.49	1004	1110	1120	1070	2.2	2.4	1.8	2.2	0.41	0.32	0.51	0.45
LSD (0.05)	ADG												0.19†			
Mean	1.10	1.12	1.06	1.08	1093	1050	1191	1143	4.2	4.1	4.2	4.1	0.66	0.62	0.73	0.73
LSD (0.05)	Mean ADG												0.07‡			
3-yr mean	1.28	1.21	1.08	1.18	1263	1243	1490	1669	5.1	4.6	4.5	5.3	0.67	0.70	0.75	0.75
LSD (0.05)	3-yr mean ADG												0.07§			

† LSD values are for fertilizer treatments in a weight date row. ‡ LSD values for yearly means. § LSD values are for 3-yr mean.

of the stocking rate increases. Stocking rate increases were made to reduce within-season differences in forage allowance (FA) and to maintain FA at comparable levels across fertilizer treatments. Forage allowance was defined as kilograms of forage DM on offer per kilogram of body weight, where the numerator and denominator, respectively, were the means of FL and stocking weights for two consecutive WD. The resultant value was used directly, i.e., it was not converted to a daily basis by dividing by the number of days between weigh dates. The management objective was to maintain FA within the numerical range of 5 to 10 kg of forage kg^{-1} of animal. Grazing was terminated when forage quality declined to a point where approximately zero gain could be estimated from previous weighings.

Initial and periodic weights were taken on all animals at 28-d intervals during fall-winter and at 21-d intervals during spring until the end of the grazing season. Derived parameters, including ADG and LG, were calculated using data from all animals.

Forage samples from both replications of the control and the 90N, 90N 34H 37S, and 67P 74S fertilizer treatments were collected during the first grazing season using two esophageally fistulated steers. The steers were placed in the field 1 d prior to the sampling day. About 1 h after dawn the following morning the steers were fitted with solid bottom collection harnesses, and eight samples per steer or 16 samples per field (treatment replication) were collected on each sampling day. Following sample collection the steers were immediately moved to the next field where they remained overnight to become accustomed to the field and resident cattle. Samples were placed in plastic bags and stored in a freezer until processed and analyzed for N and organic matter (1). In vitro disappearance of DM and organic matter (IVOMD) was measured by the two-stage procedure of Tilley and Terry (28).

Data were analyzed using analysis of variance and linear regression using Michigan State University's MSTAT and MINITAB (26). Mean separations (LSD) were performed only if *F* ratios were significant. Due to lack of significance between comparisons of individual fertilizer treatment levels (two replications), the data were combined into the three logical treatment groups of N, PS, and NPS (four replications). The only exceptions to this procedure were for forage quality data (IVOMD, N) from esophageally fistulated steer collections, where samples had been taken from only a limited number of treatments, and for LG data, where a sufficient number of individual treatment differences occurred to justify presentation. Data for LG, IVOMD, and N were all analyzed by analysis of variance. A repeated-measures analysis using BMDP-2V (4) was used for the ADG and LG data. The Geisser-Greenhouse adjustment for autocorrelation in repeated-measures analyses (6) was used to calculate effective degrees of freedom to obtain least significant differences. In determining LSD values for percent-cover differences, year effects were removed by comparing treatment values against respective control values.

Table 2. Seasonal forage production calculated by summing estimated intake (2.5% of bodyweight) and forage remaining at end of grazing season.

Treatment	1983	1984	1985	Mean
Control	3290†	2510	2490	2763§
N-only	3520	2390	2440	2783
NPS	4610	2910	2790	3437
PS-only	5690	2980	2600	3757
Treatment mean	4278‡	2698	2580	3185

† LSD (0.05) between treatments and years = 453.
‡ LSD (0.05) for treatment means between years = 226.
§ LSD (0.05) for year means between treatments = 386.

Correlation analysis was used to test for influence of uncontrolled residual variation in FL or FA on ADG using the model,

$$[F_{ytdr} - F_{ytd.}] \text{ vs. } [ADG_{ytdr} - ADG_{ytd.}],$$

where F is either FA or FL, and y, t, d, and r are year, treatment, WD, and replication, respectively. Year-linear trends in ADG over the 3-yr period were determined as adjusted ADG, removing year effects by standardizing treatment data to the control.

RESULTS AND DISCUSSION

Precipitation

The first year (1982–1983) was marked by early rainfall adequate for germination, continuity of adequate moisture throughout the winter and spring, and late rainfall interspersed with periods of bright sun (Fig. 1). The winter of 1982–1983 was of above-average temperatures, which, in combination with the well-distributed precipitation, provided excellent conditions for annual legume growth. In both of the following years rainfall adequate to sustain germination and continued growth occurred early enough to ensure at least an average start of growing season. Spring rainfall however, was only marginally adequate to sustain optimal rates of plant growth. The prolonged period of dryness from mid-December to early February in the third year, coupled with high solar radiation levels and high soil temperatures, also hastened the shift from vegetative to reproductive growth. Finally, termination of the rainfall season occurred increasingly early in the second and third years.

In Fig. 1 attention is directed to the patterns of precipitation for November and April, the two months found by Duncan and Woodmansee (5) to be best related to legume and total forage production. While November was favorable in all 3 yr of this study, April was successively less favorable in the second and third years.

Plant Responses

Dry Matter Levels and Yields. Grand mean values for FL for the 3 yr were 1965, 1160, and 1120 kg ha^{-1}, respectively (Table 1). Overall, FL was similar in the second and third years, and was less ($P < 0.01$) in both years than in the first year. The first year provided both the best set of growing conditions (Fig. 1) and the largest response to the fertilizer treatments.

In the first year annual FP for the NPS and PS-only treatments were different ($P < 0.05$) from each other and from N-only and control (the latter $P > 0.05$) (Table 2). In the second year only the PS treatment exceeded the control; in the third year there were no differences. When treatment means were combined, the first year FP exceeded both the second and third years, which were not different from each other. Combining year means showed FP from NPS and PS treatments to be greater than N-only and the control, with neither pair different from each other. While based on estimation, these data provide strong and consistent (average conversion ratio, 10.6 kg of intake kg^{-1} of gain; SD, 0.99) evidence of a major influence of PS-containing treatments on FP under grazing.

Botanical Composition. Significant ($P \leq 0.05$) departure from the control values was found only for composition of legumes for PS in the first year of the experiment (Fig. 2). Overall, grass composition trended downward over the 6-yr period (SE of slope = 0.63; $r = -0.55$). In contrast, legume composition trended upward by almost the same degree (SE of slope = 0.70; $r = 0.54$). Oscillations in year-to-year forb cover (principally filaree) resulted in an essentially zero trend. When mean values for the three species groups for the 3 yr prior to the experiment (also under grazing use) were compared to the 3 yr of the experiment, a difference ($P \leq 0.05$) was found only for the legumes in the combined PS treatments.

Apart from first-year fertilizer effects, plant composition responded principally to previous grazing management, year-to-year fluctuations caused by weather events, and possibly independent population cycles of particular species over time. These fluctuations have long been observed in the Mediterranean annual plant community (27).

Animal Responses

Experimental Conditions. Overall, stocking rates varied from 1.65 to 3.30 ha animal^{-1} during the winter period of slow forage growth, to less than 0.5 ha animal^{-1} at the time of peak forage growth and availability (Table 1). The average initial weight (3-yr mean) of individual animals was 217 kg and the average final weight was 350 kg. Therefore, the mean gain for animals present over the whole grazing season over the 3-yr period was 133 kg. This compares favorably with industry expectations under good management (20).

Stocking rate increases were made each year based on forage conditions, animal gains, and current expectations of additional seasonal forage production based on weather conditions and previous experience. Sufficient knowledge of within-season forage growth changes and related animal responses did not exist for this system to permit a more directed and precise approach. Stocking rate adjustments were intended to provide FA between 5 and 10 kg of forage kg^{-1} of animal. While FA was higher in the first year than in the second and third years, it was equalized across treatments. A superior treatment could then be identified as one with an ADG equal to or significantly higher than the control ADG at a higher stocking rate.

Because the upward adjustment in stocking rates was an integral part of system management, data from all animals were used in calculating results. The average difference in ADG for the original animals versus those subsequently added was ±0.06 kg. This influence was negligible and was outweighed by the advantage of having larger sample numbers for calculation of treatment means.

Average Daily Gains. Over the 3 yr FL remained relatively constant from the beginning of the grazing season through March, while ADG tended to increase linearly over that time (Table 1). Then, ADG stabilized at its seasonal maximum while FL increased as a result of large seasonal increases in plant growth rate. The ADG values for WD one to six (Table 1) were regressed on FL values for the same WD. The resulting r^2 for fertilizer treatments (years combined) ranged from 0.27 to 0.47. Comparable r^2 for years (fertilizer treatments combined) ranged from 0.31 to 0.61. The latter value was found for the 1983–1984 season, with the equation $Y = 0.492 + 0.00028X$; Y = ADG, X = FL. The equation for all data (WD one to six, n = 72) was $Y = 0.516 + 0.00019X$, $r^2 = 0.37$. This information suggests that ADG was influenced by factors other than FL. The strongest relationship between ADG and FL was found for the second year, perhaps because of the lower FL values in the early part of the season. Because there was much less variation in FA than in FL, no ADG-FA relationship was shown by regression analysis.

Separately, correlation analysis (which removed year, treatment, and WD influences) showed that neither residual FL nor residual FA contributed systematically or significantly to variation in ADG ($r = 0.15$, $P > 0.05$).

Winter ADG averaged for the 3 yr was approximately 0.5 kg, which increased linearly to approximately 1.0 kg by peak of season (spring) (Table 1). Combining data for the first seven WD, ADG was found to be a linear function of time ($Y = 0.394 + 0.004X$, $r^2 = 0.88$; Y = ADG, X = days). The relationship was further strengthened if only the first six WD were used ($r^2 = 0.95$). Seasonal grazing of stocker cattle is a common practice used in the annual range system to convert forage to animal product (20), yet there is almost no published information about within-season FA-ADG or FL-ADG relationships. These data provide the first such models for animal performance

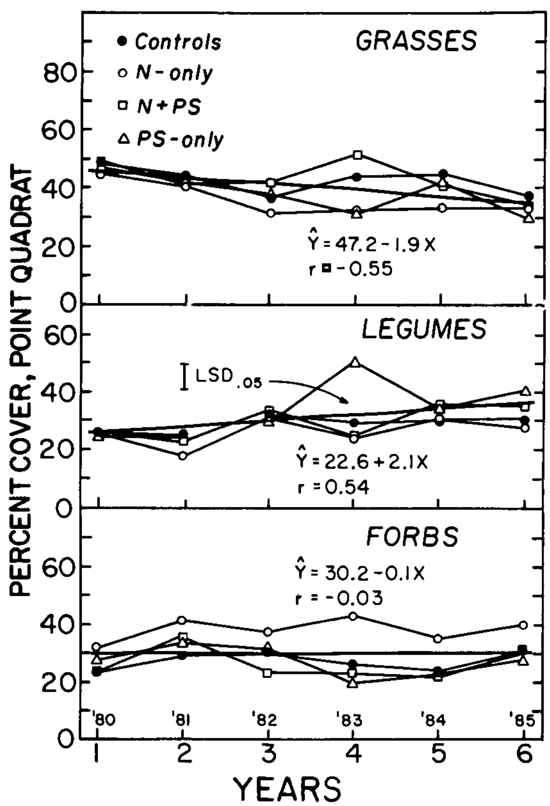

Fig. 2. Trends in percent composition of the three principal annual species groups for 3 yr prior to the experiment and the 3 yr of the experiment.

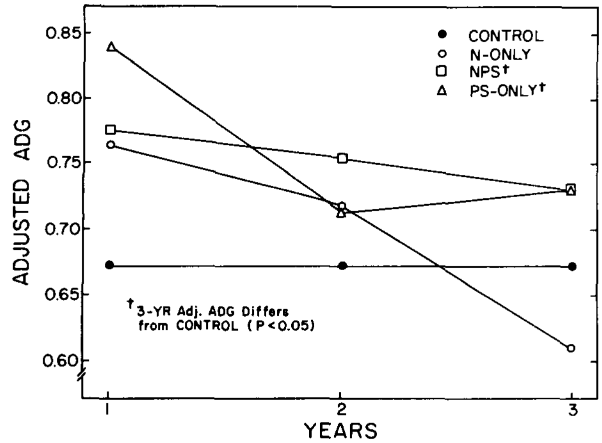

Fig. 3. Three-year trends in adjusted average daily gains. Year effects were removed by standardizing data to the control.

applicable to annual systems of similar climate, vegetation, and utilization management.

Differences in ADG related to fertilizer treatments at individual WD were few and formed no consistent pattern (Table 1). To evaluate trends of ADG response to fertilizer treatments over the 3 yr, year effects were removed by standardizing data to the control (Fig. 3). Average daily gains for NPS and PS-only were greater than ADG for the control. The N-only versus NPS, and the N-only versus PS comparisons were not significant, with $P < 0.18$ and 0.12, respectively.

Year-linear trends (Fig. 3) were not significant ($P>0.05$), although the N-only comparison had a $P < 0.12$. The near-significance of this trend was related to the fact that in the third year, seven of eight values for ADG in the N-only treatment were numerically lower than the comparable ADG values for the control (Table 1). Thus, overall, only the NPS and PS-only treatments consistently improved ADG over the control, and a time-linear decline in N-only ADG relative to the control was suggested but not established.

Seasonal Liveweight Gains. Differences in seasonal LG between treatments were substantially larger in the first year than in the second and third years (Fig. 4). In the first year LG of all treatments was significantly higher than that of the control and different for each treatment except for the 90N versus 67P 74S comparison (nonsignificant). In the second year variability between replications within a treatment was greater, and a diminished response to the fertility treatments resulted in fewer LG differences. Nitrogen carryover, as documented by Martin and Berry (17), was not found in this experiment, probably because of the high rainfall in the first season (1100 mm; Fig. 1). Previous research (12,17) in the annual system has shown diminished response to N fertilization in years of high rainfall. In the third year LG for the 45N treatment was significantly less than that for the control, and LG for the higher PS treatment was significantly higher than that for any other treatment. Next highest were the two NPS treatments, which did not differ from each other in LG but were significantly higher than the remaining treatments.

When LG was totaled for the 3 yr, the treatments formed two groups. Treatments in the first group (90N 34P 37S, 45N 34P 37S, and 67P 74S) had significantly higher ($P<0.01$) LG than any of the remaining treatments, which formed the second group. There were no differences within these two groups, which averaged 501 and 356 kg ha^{-1}, respectively.

This experiment was conducted on totally cleared lower-foothill land that is regarded as being marginally productive. A gain level of 100 kg ha^{-1} is representative of fully cleared land using good grazing management. Low-level or nutritionally incomplete fertilizer applications may not change this response very much, and if a response is attained, it will probably be short-lived. At 150 kg ha^{-1} (exceeded by four of the treatments in the first year and by the higher PS rate in the third year; Fig. 4), higher levels of fertility adjustment or favorable weather, or both, better grazing management, or a pronounced plant species composition shift (i.e., enhancement of legumes) may act singly or in combination to enable this yield increase.

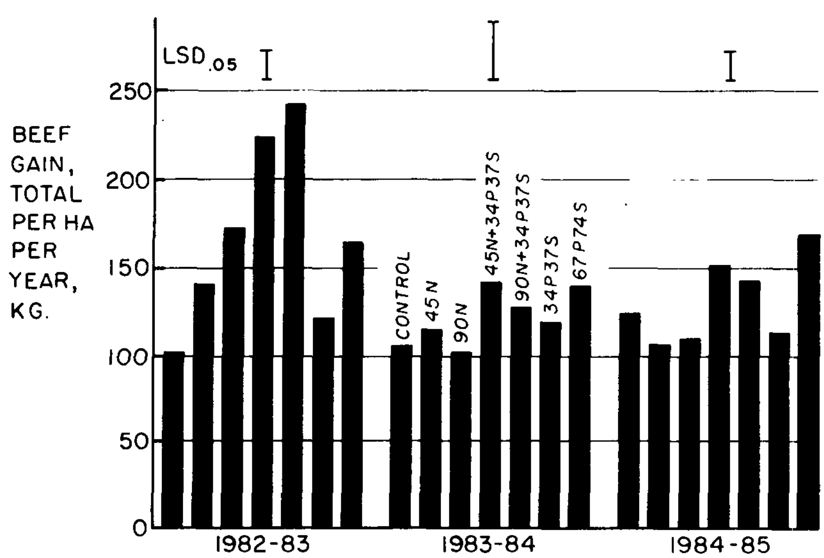

Fig. 4. Beef liveweight gains per hectare as seasonal totals for each of 3 yr.

Gains of 200 kg ha^{-1} or more occurred only in the first year and for only two of the six treatments. In this case, an excellent growing season, correction of all three major nutrient deficiencies, and high levels of stocking all contributed to this *yield-doubling* response.

The stepwise increase in stocking rate coincident with seasonal increase in forage growth rate used in this experiment is a management practice ordinarily not used by annual rangeland ranchers. An economic analysis of these data comparing income with and without increases in stocking rate after the first week of March has shown that stepwise increases can be profitable despite the need to purchase animals at seasonally prevailing higher prices (23). This suggests that efficient transfer and conversion to liveweight gain in this rangeland system depend in part on upward adjustment of stocking rate within the typical November-to-May grazing season.

Animal Gain-Forage Quality. Table 3 shows the results of organic matter digestibility (IVOMD) and N analysis of forage samples collected from the control and the 90N, 90N 34P 37S, and 67P 74S treatments by use of esophageally fistulated steers in the first year (1982–1983).

Variation in replicate values for fistula-collected samples prevented differences between individual treatment and control values from being significant within months (Table 3). When data for all treatments (including control) were combined, significance ($P<0.05$) was found for monthly means, illustrating the expected seasonal decline in forage quality. When data were combined to compare the means of the three fertilizer treatments with the control, both IVOMD and N were higher ($P<0.05$) for the fertilized treatments in March. When this comparison was made for the time interval of greatest numerical difference between the mean of fertilized treatments and control (January–April), the differences for both IVOMD and N were highly significant ($P<0.005$ and 0.007, respectively). Jones (12) concluded that N made its most valuable contribution to forage production during the winter. Jones et al. (14) also found that addition of S improved feed conversion efficiency of lambs. Fall fertilization may be justified if winter-produced forage has a high value in the livestock production system.

The presence of legumes may have resulted in a higher nutritional value for the forage overall. Each year, measurements of botanical composition were made in early April. Means of ADG for the two WD on either side of the plant sampling date were regressed on the proportions of legume, grasses, and forbs. Within-year dependence of ADG on species groups was weak or nonexistent. Regressions with $P<0.2$ were found only three times; for legumes and forbs (the latter negatively related to ADG) in the first year, and for forbs (also negative) in the third year. Therefore, legume content had a nonsignificant, albeit consistent, positive influence on ADG. It is possible that a stronger legume influence on forage quality would have existed if the range of legume percentages had been wider or if a nonlegume control had been available.

The influence of grasses and forbs on ADG was mixed and also nonsignificant. The highest probability associated with an ADG-species group regression ($P<0.13$) was found for the negative influence of forbs in the third year. Overall, variation in legume content tended to be associated more with variation in forb content than with variation in grass content.

Table 3. In vitro organic matter disappearance (IVOMD) and N concentrations in forage samples from esophageally fistulated steers grazing control and selected fertilizer treatments during the 1982–1983 season.

	Treatment				
Month	Control	90N	90N 34P 37S	67P 74S	Mean
	$g\ kg^{-1}$				
	IVOMD				
January	636	684	701	688	677
February†	-	730	710	732	724
March	675	718	718	753	716
April	663	692	694	724	693
May	629	618	662	614	631
June	482	505	532	522	510
July	562	576	584	543	566
Mean	608	646	658	654	645
LSD (0.05)‡					52
	N				
January	23.2	23.3	34.3	29.2	27.5
February†	-	33.7	29.7	38.3	33.9
March	24.3	34.7	32.1	36.5	31.9
April	21.0	21.9	25.2	34.3	25.6
May	15.8	17.3	18.1	20.1	17.8
June	8.2	11.8	11.2	15.8	11.8
July	7.8	10.6	12.3	10.6	10.3
Mean	16.7	21.9	23.3	26.4	22.1
LSD (0.05)‡					3.5

† Values are for one replication only.
‡ LSD values test differences between months in the column of treatment means.

CONCLUSIONS

Fertilization of a mixed grass-legume-forb annual range plant community with N, PS, or NPS significantly increased per-unit-area steer liveweight gains. Increases were greater with either NPS or PS treatments than with N-only, and were greater in the first year than in the second and third years. Annual and within-year precipitation patterns probably influenced these results. The most important component of this increase in gain was probably a general increase in forage production, which in turn was effectively transferred by means of within-season increases in stocking rates.

Average daily gains formed a characteristic seasonal pattern beginning with a linear increase from December to about 1 April, followed by a 28- to 42-d plateau and a sharp decline at plant maturity. Gains were significantly improved by fertilization, especially by the NPS and PS treatments. Differences in within-season forage levels and between-treatment legume, grass, and forb proportions, as they occurred in this experiment, had smaller effects on ADG.

Animals grazing fertilized treatments appeared to select a diet that was more digestible and contained more N during winter and early spring compared to the unfertilized control.

The most important single management factor indicated by the results of this experiment was attention to efficient transfer of additional forage produced through seasonal regulation of forage allowance by increases in stocking rate. Forage allowances maintained between 5 and 10 kg kg^{-1} are suggested as a criterion until refined by additional research.

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